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Tectonostratigraphic development of the Trondheim region Caledonides, Central Norway

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Abstract—The metamorphic allochthon of the central Norwegian Caledonides comprises a complex of discrete nappes of metasediments and igneous rocks ranging in age from probable Svecofennian through Vendian to Silurian. This southeastward-translated allochthon overlies a thin cover of autochthonous Vendian to Cambrian sediments deposited upon a crystalline Precambrian basement, and is superseded by late-orogenic, intermontane-basinal sediments of latest Silurian to Middle Devonian age. Stratigraphical sequences in higher allochthonous units are floored by oceanic tholeiitic basalts with rare, subjacent sheeted-dyke and gabbro units, considered as fragments of an ophiolite assemblage which suffered initial eastward transport in pre-Middle Arenig times, an important orogenic event which is well represented in northern and southwestern Norway. The overlying Ordovician–Silurian sequences, disturbed by episodic parorogenic events, embrace a variety of sedimentary facies from shallow-water carbonates to deep-marine terrigenous turbidites and include both island arc and marginal basin lavas and intrusives. Polyphase Middle Silurian metamorphism and deformation resulted in a complex telescoping and dissection of the Lower Palaeozoic rocks and their Precambrian substrate, with nappe translation in the order of several hundred kilometres. Folding and thrusting of Old Red Sandstone molasse sediments attests to continuing tectonism well into Devonian times.

INTRODUCTION

THE TECTONIC structure of the Caledonian metamorphic allochthon in Norway comprises a succession of thrust sheets composed of a variety of metasedimentary and igneous rocks of wide-ranging age, from Middle Proterozoic through to Silurian. Nappe translation, east to southeastward on to the Fennoscandian or Baltic Shield, and internal tectonometamorphic reconstitution were both polyphasal and diachronous, though with two principal evorogenic episodes: (1) *Finnmarkian* (late Cambrian–early Ordovician); and (2) *Scandinavian* (mid-late Silurian). Recent syntheses of Norwegian Caledonian deformation have been given by Sturt (1978) and Roberts & Sturt (1980), and general reviews presented by Nicholson (1979) and Oftedahl (1980).

With its favourable exposure of nappe stratigraphy flanking antiforms cored by basement crystalline rocks, the Trondheim region of central Norway provides instructive profiles through the orogen. Deeply incised valleys normal to the strike have allowed easy access and facilitated the development and extension of the theory of nappe tectonics in this region and neighbouring Jämtland, in Sweden, almost a century ago (Törnebohm 1888, 1896). Asklund (1938) may be credited as being the first to indicate widespread overthrusting for the rocks of the Trondheim region. The major thrust plane was depicted in the area of the Grong culmination by Oftedahl (1956), whereas Peacey (1964) ventured an autochthonous interpretation for the cover-upon-basement contact in the Tømmerås district. Wolff (1967), following Asklund (1938) and Strand (1961), considered the bulk of the Lower Palaeozoic sequence occupying the Trøndelag basement depression as allochthonous, employing the term Trondheim Nappe. Later recognition of internal thrusting (Guezou *et al.* 1972, Gale & Roberts 1974) led Guezou (1978) into upranking this to Trondheim Nappe Complex; and in the Tømmerås area Gee (1977) reported the occurrence of far-travelled nappe units above thin, autochthonous sedimentary cover.

The present account deals principally with the tectonostratigraphy and sequential development of the multilayered allochthon in this part of the Caledonian orogen, though with greater emphasis placed on the Trondheim Nappe Complex. For a more comprehensive bibliography the reader is referred to papers by Vogt (1945), Wolff (1967, 1979), Roberts (1967, 1978), Rui (1972), Guezou (1978), Nilsen (1978) and Wolff & Roberts (1980).

TECTONOSTRATIGRAPHY

The sequence of nappes, emplaced above autochthonous or parautochthonous Precambrian crystalline basement and a thin cover of Vendian–Lower Palaeozoic sediments, and itself forming the substrate to late-orogenic Old Red Sandstone sediments, has been identified largely in central and northern districts (cf. Wolff 1976), and is summarized in Table 1. Two major allochthonous complexes, upper and lower, are recognised. Of these, the lower complex is developed on only a comparatively local scale, peripherally to the upper allochthon. For purposes of description, correlative tectonic units in the lower allochthon from eastern and western areas are treated as one nappe. To the southeast of the region the arkosic rocks of the so-called 'sparagmite basin' are now

Table 1. Tectonostratigraphy of the Trondheim region

Tectonostratigraphy	Northern & central districts: Western areas	Northern & central districts: Eastern areas	Oppdal district	Dombås and southern districts	Units in Sweden
Old Red Sandstone	?Ludlovian–Mid. Devonian sediments	Lower Devonian sediments			
Upper allochthonous complex	Trondheim Nappe complex {Støren, Gula}	Meråker Gula	Tronget	Trondheim Nappe complex	Köli Seve
Lower allochthonous complex	Levanger Skjøtingen Leksdal {Leksdalsvatn, Hærvola}	Øyfjell Essandsjø Remsklepp	Blåhø Sætra Risberget	Andbergshøi: Bottheim Veslfjell	Köli Seve Särv Offerdal Tännäs
Basal allochthon			Amotsdal	Osen–Røa Nappe complex	Jämtland
Parautochthon and autochthon	Cover sediments Precambrian crystalline basement		Precambrian basement	Cover sediments Precambrian basement	Cover sediments Precambrian basement

Sources: northern and central districts, several references noted in the text; Oppdal district, Krill (in press); Dombås and southern districts, Guezou (1978), Nystuen (in press); Swedish units, Gee (1975). Primary unconformable contacts exist at the base of the Old Red Sandstone sequences, and below the autochthonous cover sediments. All other contacts are tectonic.

considered as long-transported, and thus constitute what we term the basal allochthon (Table 1).

Autochthon and parautochthon

In this category there are two principal rock associations: (a) crystalline rocks of the Precambrian (Svecofennian, 1700–1600 Ma) basement and (b) a thin platform-cover sequence of latest Precambrian to Cambro-Ordovician sediments.

(a) The basement crystalline rocks occurring in the coastal 'western gneiss region' and in antiformal windows (e.g. Tømmerås) and culminations (e.g. Grong–Olden) have traditionally been considered as autochthonous, although there is still uncertainty over this question. The Olden Massif (Stephansson 1976) in the extreme northeast (Fig. 1), with its porphyritic rhyolites and granites, is probably closest to being *in situ*, but similar rocks coring windows are variably foliated, with minor thrusts, and best regarded as parautochthonous. The polydeformed 'western gneisses' are more problematical. The older view that their high-grade metamorphism was Caledonian has been rejected by Pidgeon & Råheim (1972) and Råheim (1977) in favour of a Svecofennian age. Whereas Råheim (1977) considers the Caledonian influence to have been minimal, other workers recognise a penetrative Caledonian fold-deformation in this gneiss region (Wolff 1976, Krill in press). Moreover, the possibility of major post-metamorphic allochthoneity for the western gneissic basement and some cover units has been raised by the results of a recent seismic study (Mykkeltveit 1980).

(b) Thin quartzites, phyllites and local limestones of probable Vendian to Lower Ordovician age rest unconformably upon the crystalline basement rocks of the Olden Massif and Tømmerås antiform (Gee 1974, 1977). Depending on the character of their immediate substrate they may be either autochthonous or parautochthonous.

Basal allochthon

In the southeastern corner of the region (Fig. 1), low-grade Late Precambrian sandstones, shales, limestones and tillite of the 'sparagmite basin' are extensively exposed beneath the higher grade allochthonous units. Recent work has tended to favour an allochthonous interpretation (Osen–Røa Nappe Complex) for this thick basinal sequence (Hossack 1978, Nystuen in press), following the initial ideas of long-distance transport forwarded by Oftedahl (1943). Similar sandstones occur near Oppdal (Krill in press). Nystuen (in press) has estimated a minimum translation of 150 km for this nappe complex.

Lower allochthonous complex

The lower allochthonous complex (LAC) (Wolff & Roberts 1980) is represented by irregular or lensoid occurrences around the periphery of the upper allochthonous complex (UAC), either directly upon parautochthonous cover or basement in northern areas, or upon the basal Osen–Røa Nappe Complex in the south.

Leksdal–Remsklepp Nappe. This composite nappe unit (Table 1) consists largely of meta-arkoses and sandstones with subjacent augen gneisses and blastomylonites (Wolff 1976, 1979). The rocks are locally strongly tectonized and are quarried as flagstones in several areas. Metadolerite dykes occur profusely in places in the psammites (Andreasson *et al.* 1979). At Oppdal, dolerite-intruded psammites (Sætra unit) tectonically overlie augen orthogneisses and rapakivi-type granite (Krill in press). Similar units occur further south near Dombås (Guezou 1978). In the Tømmerås district we have recognised comparable lithotectonic elements in subdividing the Leksdal Nappe into the Leksdalsvatn (upper) and Hærvola tectonic units (Table 1). These are likely correlatives of the Särv–Offerdal and Tännäs Nappes, re-

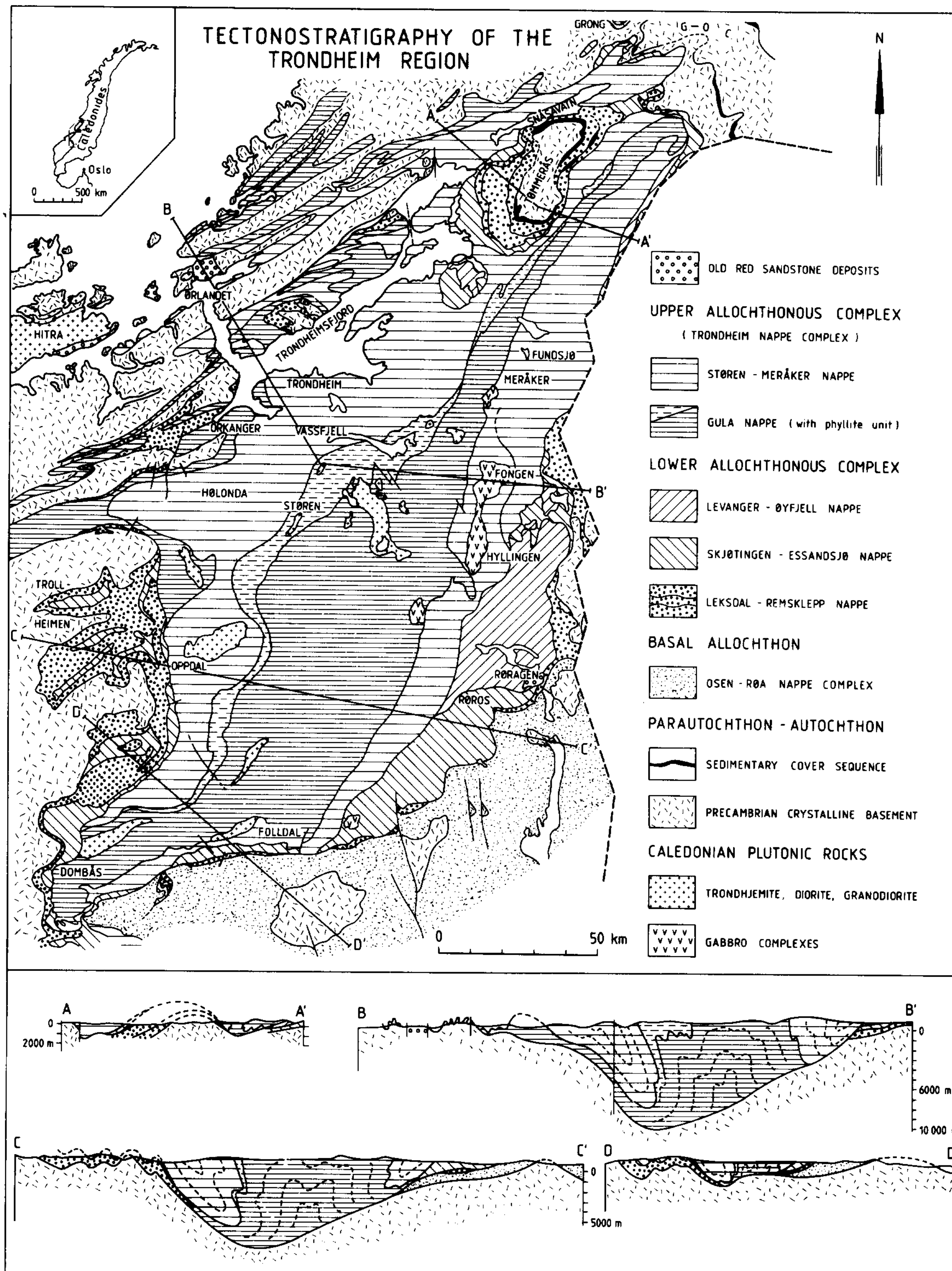

Fig. 1. Simplified tectonostratigraphic map of the Trondheim region Caledonides, with four cross-sections. The map is based on Wolff (1979) though with appreciable revision taken from NGU 1 : 50,000 preliminary and manuscript maps and from Andreasson *et al.* (1979), Gee (1977) and Krill (in press). The situation in the northwestern part of the region is the most problematical particularly with regard to distinguishing between the lithologies of the Gula and Skjøtingen–Essandsjø Nappes. In some areas both of these tectonic units may be present, with or without a thin intervening sliver of Levanger–Øyfjell rocks. Almost all contacts shown are tectonic; exceptions include those bordering Old Red Sandstone deposits, those at the base of the autochthonous cover sediments, and the contacts of igneous massifs.

In the cross-sections the vertical scale is exaggerated three times to help distinguish the different units. Depth to basement has been calculated from the available geophysical data.

spectively, of Sweden (Gee 1975). Metadolerite dykes from Oppdal have yielded a Rb–Sr isochron age of 745 ± 37 Ma. (Krill in press), interpreted as an intrusive age.

Skjøtingen–Essandsjø Nappe. Rock-types in this tectonic unit are principally amphibolites and garnet-mica schists with subordinate quartzites and small serpentinised ultramafite bodies (Wolff 1976, 1979). In addition, thin marble bands are present near Oppdal (Blåhø unit, Krill in press). Metakeratophyres are intercalated with the amphibolites around Dombås (Bottheim unit of the Andbergshøi Complex, Guezou 1978), together with some gneisses and marbles. Kyanite grade has been attained in the Oppdal–Dombås district.

The rocks of the Skjøtingen–Essandsjø Nappe have been considered by us, on the basis of lithological similarity, as lower-level tectonic slices of the Gula unit of the Trondheim Nappe Complex. In terms of structural position and lithology the Skjøtingen–Essandsjø Nappe is thus comparable to the Seve Nappe of Sweden.

Levanger–Øyfjell Nappe. Consisting predominantly of hornblende–garben schists, locally garnetiferous (Wolff 1976, 1979), this nappe unit occurs in the north and southeast of the region (Fig. 1). The lithology commonly resembles an interbanded metagreywacke and pelite and, as such, and in view of its structural position, it is considered to be a correlative of the Köli Nappe of Swedish terminology (Wolff & Roberts 1980).

Upper allochthonous complex

The bulk of the metamorphic and locally fossiliferous rocks occupying the wide basement depression of Trøndelag constitute the UAC, which is essentially the same as the Trondheim Nappe Complex. Two main nappe units are recognised—the Støren and Gula Nappes—although this basic tectonostratigraphy is complicated by internal thrusts in some areas (Guezou 1978, Oftedahl 1979).

Gula Nappe. A heterogeneous sequence of various gneisses, garnet ± kyanite ± sillimanite schists, migmatites and amphibolites with minor marbles, quartzites, quartzite-conglomerates and sporadic serpentinised ultramafite bodies constitutes the Gula Group or Complex. The Gula is extensively exposed in a NE–SW zone in the central part of the UAC (Fig. 1) in the core of an antiformal structure, and reappears to the west beneath the overlying Støren Nappe. Its precise extent in isolated outliers in the northwestern parts of the region is problematical, since it can readily be confused with rocks of the Skjøtingen–Essandsjø Nappe. The age of the Gula Complex is uncertain and it is not impossible that rocks of more than one orogenic cycle from Precambrian to Ordovician are represented (Roberts & Sturt 1980). Low-grade phyllites, with Tremadocian fossils in one area in the east (Vogt 1940), have also been regarded as part of the Gula Nappe, but are possibly best considered as a separate unit (Fig. 1). Similar phyllites with banded cherts occur to the west of the central outcrop of the higher grade Gula Nappe and in tectonic contact with the latter. These rocks have been considered as part of a mélange (Horne 1979), though not without reservations (Roberts 1980). They have also been interpreted as a tectonic wedge of Lower Hovin Group rocks (Wolff 1976, 1979).

Støren–Meråker Nappe. A generally low- to medium-grade volcanosedimentary succession of probable Cambrian to Llandoverian age comprising four main groups within the Trondheim Supergroup, constitutes the highest major nappe in the region—the Støren Nappe, and its eastern counterpart, the Meråker Nappe. This includes the classical stratigraphy (Støren, Lower Hovin, Upper Hovin and Horg Groups) of the Hølonda–Horg area (Vogt 1945) with its rich fauna of brachiopods, trilobites, graptolites and molluscs. Successions of similar lithology in the Meråker part of the Trondheim Supergroup may or may not be directly comparable to the Hølonda group divisions; facies changes are apparent even over quite small areas. In this short synthesis no distinction is made. More detailed descriptions are contained in Siedlecka (1967), Wolff (1979) and Wolff & Roberts (1980).

The Støren Group is dominated by pillowed basaltic greenstones of ocean-floor tholeiitic character (Gale & Roberts 1974). The 2.5–3.0 km thickness also includes thin jaspers, cherts, hemipelagic phyllites and quartz keratophyres. A well preserved fragment of an ophiolitic assemblage (gabbro, 100% sheeted dykes, lavas) has been discovered (Grenne *et al.* 1979) on Vassfjellet. This particular unit has generally been considered as a correlative of the Støren Group, but this is not proven. In terms of age the Støren Group lavas probably range from a minimum of early Arenig down to the Early Cambrian. In the east (Meråker unit) the volcanite sequence (Fundsjø Group), which is assumed to be broadly correlative with the Støren Group, contains both low-K tholeiites and ocean-floor basalts (Vokes & Grenne 1978), and acidic effusive material is much more in evidence (Chaloupsky & Fediuk 1967).

The Lower Hovin Group (and its eastern equivalent) commences with a basal polymict conglomerate containing clasts derived mainly from the weakly deformed and metamorphosed Støren–Fundsjø unit. The group (Lower to Middle Ordovician) otherwise contains metasandstones, pelites, limestones, conglomerates, greenstones and tuffs of generally shallow-marine back-arc origin. Local spreading centres accreting tholeiitic basalts are also known. Porphyritic andesites are present in the Hølonda area in association with limestones. Upper Hovin Group rocks comprise flysch-type metagreywackes, intraformational conglomerates and pelites, indicating a deeper-marine environment in Late Ordovician times. The status of the Horg Group is contentious (cf. Chaloupski 1970). The rocks are metasandstones and slates or phyllites. In the correlative Meråker unit (Slågån Group) graptolites of Llandoverian age are known (Getz 1890).

TECTONIC STRUCTURAL SEQUENCE IN THE NAPPES

The greater part of the polyphase folding and metamorphism represented in the several nappes of this region can be dated as approximately Middle Silurian (Roberts 1967, Wilson *et al.* 1973). The youngest fossiliferous rocks involved in this major deformation are of Llandoverian age, while in the west the oldest molasse sediments of the Old Red Sandstone possibly extend down into the Ludlovian.

Despite common similarities of style, geometry and trend, of particularly the earliest minor folds from nappe to nappe, the basic diachroneity of the allochthon displacement denies the likelihood of any strict inter-nappe correlation. Broad comparisons may of course be made, for example on the basis of relationships to a regionally common schistosity. Complications arise too from the realisation that primary syn-depositional isoclines of several metres amplitude recognised in low-grade sediments in several areas (Roberts 1972) may be misidentified as 'early' tectonic folds in higher-grade sequences. For these reasons we confine this brief account of tectonic structures to the Trondheim Nappe Complex.

Translation of the Støren unit upon the Gula Nappe was initially considered as pre-dating the earliest Silurian folding (Gale & Roberts 1974). Recent work on ophiolites in west and central Norway has narrowed down the time of probable obduction of the metabasalts to pre-Middle Arenig (Furnes *et al.* 1979), and much evidence has now accumulated for an early Ordovician (Finnmarkian) tectonothermal event (Guezou 1978, Bruton & Bockelie 1980, Ryan *et al.* 1980, Lagerblad in press) involving the juxtaposition of the Støren/Fundsjø magmatic assemblages and the subjacent Gula unit (see also Sturt *et al.* 1967). Internal thrusting has also produced tectonic repetition of the Støren/Fundsjø units in some areas.

Considering the UAC as a whole, 5 or 6 fold-deformation phases have been recognised by various workers, of which the earliest appears to be confined to the sub-Lower Hovin sequence. Even within any one area "problems in the correlation of mesoscopic structures abound" (Olesen *et al.* 1973), yet there is now a reasonable consensus that the regionally-developed Silurian foliation relates to the *D*2 episode. Folds of this phase, both minor and major, are generally isoclinal, as are the earlier, 'Finnmarkian' *D*1 folds. There are also uncommon pre-*D*2 Silurian folds in some areas which may be either primary or tectonic structures. The syn-foliation *D*2 folds show an almost ubiquitous association with a fairly penetrative ESE–WNW lineation which relates to the overall progressive simple shear deformation, with the mesoscopic fold rotation that accompanied allochthon development (Roberts & Sturt 1980). This is most prominent in the zones of late-*D*2 high ductile strain along nappe boundaries. Increments of flattening and stretching, induced by the accreting nappe pile, then assisted in developing nappe lenticularity ('mega-boudinage', Gee 1978), particularly in those units lower down in the succession. This was followed by *D*3 fold development, mostly open, fairly upright, NE–SW antiforms and synforms of regional importance (e.g. the Tømmerås structure). This phase may have commenced earlier in the west and thus be partly coeval with continuing nappe translation in areas further to the east. Within the Trøndelag depression the central antiformal structure (Wolff 1967) deforms the *S*2 foliation (Olesen *et al.* 1973), and develops southwards into a series of smaller and tighter antiforms and synforms with some thrust dissection, notably near Dombås (Guezou 1978). West of the antiform a major *D*2 recumbent syncline faces west, attesting to the complexity of the internal structure of the allochthon.

After the construction of the nappe pile (*D*2), and its initial post-thrusting deformation (*D*3), there followed a phase of gravitational collapse which produced abundant, mainly mesoscopic folds (*D*4) with a flat-lying axial surface crenulation cleavage, recognised both within and outside the Trondheim region (Roberts 1967, 1971, 1978). The geometry, symmetry and character of these structures, which do not affect younger Devonian sediments, show interesting relationships to the pre-*D*4 attitude of foliation and layering (Roberts 1971). Later structures include a variety of kink folds, transverse warps, shear zones and faults. One particular kink band set is regionally extensive and of consistent N–S trend, denoting horizontal shortening transverse to the orogen.

CALEDONIAN INTRUSIVE ROCKS

A variety of late Precambrian to Lower Palaeozoic intrusive rocks ranging from acidic to ultrabasic composition are present within the tectonostratigraphy, with particular rock-types tending to associate with specific tectonic units. Ultramafites occur most commonly in rocks of the Skjøtingen–Essandsjø Nappe and in places in the Gula Nappe, generally as scattered, small, lensoid serpentinised bodies. The age of these bodies is unknown; they may range from Precambrian to early Ordovician. Ultramafic rocks are also found in association with some of the gabbro complexes. Gabbroic rocks occur mostly within the upper allochthon in both Gula and Trondheim Supergroup rocks, either as constituent parts of ophiolite assemblages (Grenne *et al.* 1979), as synorogenic (Silurian *D*1–*D*2) petrologically complex intrusions (Nilsen 1973), or as scattered lensoid bodies.

Trondhjemites, diorites and monzonites of several intrusive phases are largely restricted to Gula, Støren and Fundsjø Group rocks. Size (1979) reached the conclusion that the type trondhjemite, from Follstad near Støren, was derived by anatectic equilibrium melting of a subducting, K-poor, tholeiitic basalt. Less common plagiogranites are associated with Støren–Fundsjø Group magmatic rocks. Other occurrences are described by Size (1979) and Wolff (1979).

Metadolerite dykes attain greatest prominence in the flagstones of the upper subnappe of the Leksdal–Remsklepp unit (p. 488). Both tholeiitic and alkaline types are represented (Andreasson *et al.* 1979). Another important occurrence of tholeiitic dolerites is that of sheeted dyke complexes within ophiolite 'stratigraphy' (Grenne *et al.* 1979, Grenne 1980 and unpublished data). These are undoubtedly younger (Vendian to Cambrian for Støren/Vassfjell units) than those cutting the flagstones.

OLD RED SANDSTONE DEPOSITS AND THEIR DEFORMATION

Molasse deposits of late Silurian–Downtonian to Middle Devonian age occur in western coastal districts (Siedlecka & Siedlecki 1972, Siedlecka 1975) and comprise sandstones, conglomerates and mudstones of intermontane-basinal alluvial-fan and braided-stream origin. Similar Old Red Sandstone sediments are exposed at Røragen in the southeast of the region; these are of Lower Devonian age.

At Røragen, the Old Red Sandstone deposits were open-folded about E–W to NE–SW axes, with very low-grade metamorphic crystallisation; subsequent kinking, thrusting and faulting of the rocks includes some NW-directed movements. The E–NE fold trend is recognised in the Devonian basins of western Norway, and also in the major 'Faltungsgraben' southwest of the Trondheim region.

In the coastal district, including Hitra (Fig. 1), NE–SW trending open to close synclines are represented with axial and transverse fault sets (Siedlecka & Siedlecki 1972). A prominent cleavage, axial planar to folds, is also present in some of the mudstones (D.R., unpublished data) and this has been kink-banded.

The deformation structures in the Old Red Sandstone rocks, both in the west and at Røragen, are generally considered to be of immediately post-Middle Devonian age, equivalent to the Svalbardian movements of Vogt (1936), although there are no close stratigraphic constraints on this timing. Some of the faults, initially syndepositional, may however be of Jurassic and Tertiary age (Siedlecka & Siedlecki 1972, Oftedahl 1975).

GEOPHYSICS

A study of the available geophysical data has been carried out (Wolff, in prep.) in an effort to determine the deep structure of the region. A few of the main features are noted here. A magnetic anomaly map of the area shows an increase in magnetic values both in the east and in the west, and a positive anomaly also coincides with the Tømmerås antiform. Magnetic susceptibility measurements of about 300 rock specimens from selected parts of the region, together with the general knowledge that the Precambrian crystalline rocks usually show higher magnetic values than those of the Palaeozoic sequences, demonstrate clearly that the Precambrian basement is downwarped in a structural depression beneath the Caledonian allochthons in the central parts of the region.

A gravity anomaly map shows an increasing positive gravity anomaly towards the coastal and shelf areas to the west, a feature which has been interpreted as relating to a thinning of the continental crust; this thinning was presumably associated with the opening of the Atlantic Ocean. A coastal gradient has been inferred based on this assumption. Steeply diminishing gravity values towards the east derive from the presence of light granitic rocks of the Precambrian basement in an antiformal ridge along the border between Norway and Sweden. A steep negative gradient around the Tømmerås dome also relates to the penetration of the Caledonian allochthon by lighter Precambrian crystalline rocks. Density determinations of some 300 rock specimens support these interpretations in showing markedly higher specific gravity values for rocks of the allochthonous complexes than for the Precambrian basement crystalline rocks.

Based on the above data, a computer model of the form and depth of the basement to the Palaeozoic allochthon has been determined. Depending on the parameters applied, the most likely maximum thickness of allochthonous cover is between 8 and 12 km (Fig. 2).

CALEDONIAN EVOLUTION

In this account, concluding remarks aimed at synthesizing the development of the orogen in this part of the Caledonides are purposely brief. Aspects of the evolutionary models proposed and illustrated by Gale & Roberts (1974) and Gee (1975) still hold, though with refinements occasioned by more recent research and discoveries. In this regard, significant pointers have been provided in several of the papers cited above, and much data are yet unpublished.

Acceptance of a southeastward displacement of some of the thrust sheets by up to several hundred kilometres from their pre-orogenic locations (Gale & Roberts 1974, Gee 1975, 1978) permits an assessment of the palaeogeography of the depositional and magmatic environments in which the various rock-units accumulated. Transport distances for the basal allochthon alone are conservatively estimated at from 100 km (Hossack 1978) to 150 km or more (Nystuen in press). These rift-basin sediments, originally marginal to the Fennoscandian Shield, are themselves overthrust by basement gneisses and granites and these in turn by dolerite-intruded sandstones of the upper Leksdal–Remsklepp and Saetra units. The dykes are generally considered as signifying a very early rifting phase in the development of Iapetus (Gee 1975, Andreasson *et al.* 1979). We consider the gneiss nappe (basal part of the Lekdsdal–Remsklepp) as representing slices of a pre-existing basement high or continental ridge separating major basins; a similar idea having been reported by Prost *et al.* (1977). Thrust above these lower units from a more internal orogenic zone are epicontinental to miogeoclinal Gula/Seve rocks and overlying, generally deeper-marine, Trondheim Supergroup volcanites and sediments, in both the LAC and UAC. It is the latter sequence which contains the ocean-accreting ophiolitic assemblages and unconformably overlying sediments bearing a mainly American fauna in the west (Bruton & Bockelie 1980).

Working forward in time through the stages of Caledonian evolution in Trøndelag, latest Precambrian to Cambrian ocean opening gave way to an early (or first) subduction phase (Late Cambrian) with immature volcanic-arc products interdigitating with ocean-floor basalts in eastern areas (Fundsjø). Obduction of Støren

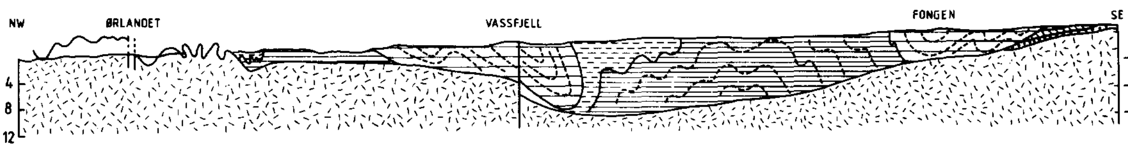

Fig. 2. Computer-modelled WNW–ESE profile across the central part of the Trondheim region based on the available geophysical data. The profile corresponds approximately to line *B–B′* on Fig. 1: no vertical exaggeration. The ornament is that used in Fig. 1, though with an approximately 50% reduction factor.

oceanic crust plus these early arc rocks in pre-Middle Arenig time upon a Gula substrate, with possible subjacent mélange development, is broadly coeval with the initial folding (*D*1) and metamorphism recorded in these rocks; trondhjemites, derived from the earlier subduction and anatectic melting penetrate the Gula/Støren couplet from latest Cambrian time onwards. Some of the internal thrusting within the Gula and Skjøtingen–Essandsjø Nappes, and even their initial displacement, may conceivably relate to this early Ordovician (Finnmarkian) orogenic phase, with the Støren ophiolitic material representing the highest structural slice.

Ordovician to early Silurian time saw the construction of a volcano-sedimentary stratigraphy unconformably upon the uplifted and partly eroded ophiolite and its Gula substrate, in a gradually deepening oceanic basin, initially at least of back-arc character. Basin instability is recorded in 3 or 4 parorogenic episodes, one or more of which may relate to incipient nappe detachment known from elsewhere in Norway. At other times, ocean accretion in the marginal basin regime was in operation (Grenne & Roberts in press). The mature, evolved arc was situated further west (on Smøla, just west of Hitra) above the second, major, (east-dipping) subduction zone. Arenig–Llanvirn fossils in the Hølonda and Smøla areas are mostly of American affinity (Bruton & Bockelie 1980), although the rocks themselves are unlikely to have been deposited along the western margin of Iapetus (Roberts 1980).

The principal, multiphase, evorogenic deformation and metamorphism of all these rock sequences—the plate collisional phase—began in Middle Silurian time, with allochthon displacements being diachronous and roughly from WNW to ESE. Nappe stacking post-dates the isoclinal folding, penetrative foliation and metamorphic peak, and produced inverted metamorphic zonations (Andreasson & Lagerblad 1980). Internal thrusting may have been complex and polyphasal. A more homogeneous strain, flattening with continued extension, followed the initial rotational simple shear and led to major boudinage of the nappe pile, with a general westward thinning and excision of many units. Later deformation included major upright synforms and antiforms, and younger flat-flying gravity collapse folds, shear zones and kink structures.

Molasse sedimentation commenced in latest Silurian time in the west, simultaneous with continuing nappe movement further east, in Sweden. Syn-depositional strike–slip and normal dip–slip faulting characterised the Downtonian–Middle Devonian period in Trøndelag, although at deeper levels southeastward translation was still occurring. By early Upper Devonian time compressive deformation had left its mark on the Old Red Sandstone sediments, carried the basal allochthon into its present location, and produced the Jura-style folding and décollement tectonics of the Lower Palaeozoic sediments in the Oslo rift basin further to the southeast.

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REFERENCES

Andreasson, P. G. & Lagerblad, B. 1980. Occurrence and significance of inverted metamorphic gradients in the western Scandinavian Caledonides. *J. geol. Soc. Lond.* **137**, 219–230.

Andreasson, P. G., Solyom, Z. & Roberts, D. 1979. Petrochemistry and tectonic significance of basic and alkaline-ultrabasic dykes in the Leksdal Nappe, northern Trondheim region, Norway. *Norg. geol. Unders.* **348**, 47–71.

Asklund, B. 1938. Hauptzüge der Tektonik und Stratigraphie der mittleren Kaledoniden in Sweden. *Sver. geol. Unders.* **C-417**.

Bruton, D. L. & Bockelie, J. F. 1980. Geology and paleontology of the Hølonda area, western Norway—a fragment of North America? *Proc. IGCP Symp.* Blacksburg, Virginia, 41–47.

Chaloupsky, J. 1970. Geology of the Hølonda–Hulsjøen area, Trondheim region. *Norg. geol. Unders.* **266**, 277–304.

Chaloupsky, J. & Fediuk, F. 1967. Geology of the western and northeastern part of the Meråker area. *Norg. geol. Unders* **245**, 9–21.

Furnes, H., Roberts, D., Sturt, B. A., Thon, A. & Gale, G. H. 1979. phiolite fragments in the Scandinavian Caledonides. *Proc. Int. Ophiolite Symp. Nicosia*, Geol. Surv. Cyprus, 582–600.

Gale, G. H. & Roberts, D. 1974. Trace element geochemistry of Norwegian Lower Palaeozoic basic volcanics and its tectonic implications. *Earth Planet. Sci. Lett.* **22**, 380–390.

Gee, D. G. 1974. Comments on the metamorphic allochthon in northern Trøndelag, Central Scandinavian Caledonides. *Norsk geol. Tidsskr.* **54**, 435–440.

Gee, D. G. 1975. A tectonic model for the central part of the Scandinavian Caledonides. *Am. J. Sci.* **275**, 468–515.

Gee, D. G. 1977. Extension of the Offerdal and Särv Nappes and Seve Supergroup into northern Trøndelag. *Norsk geol. Tidsskr.* **57**, 163–170.

Gee, D. G. 1978. Nappe displacement in the Scandinavian Caledonides. *Tectonophysics* **47**, 393–419.

Getz, A. 1890. Graptolitførende skiferzoner i det Trondhjemske. *Nyt Mag. Naturvid.* 3· 41–42.

Grenne, T. 1980. Vassfjellet area. In: *Excursions Across Part of the Trondheim Region, Central Norwegian Caledonides.* (edited by Wolff, F. C.) *Norg. geol. Unders* **356**, 159–164.

Grenne, T., Grammeltvedt, G. & Vokes, F. M. 1979. Cyprus-type massive sulphides in the western Trondheim region, central Norwegian Caledonides. *Proc. Int. Ophiolite Symp. Nicosia*, Geol. Surv. Cyprus.

Grenne, T. & Roberts, D. 1980. Geochemistry and volcanic setting of the Ordovician Forbordfjell and Jonsvatn greenstones, Trondheim region, Central Norwegian Caledonides. *Contr. Miner. Petrol.* **75**.

Guezou, J.-C. 1978. Geology and structure of the Dombås–Lesja area, southern Trondheim region, South-central Nørway. *Norg. geol. Unders.* **340**, 1–34.

Guezou, J.-C., Poitout, M.-J. & Santarelli, N. 1972. Le complexe de Trondheim et son soubassement dans la règion de Lesja–Dombås (Oppland, Norvège centrale). Aperçu structurale et lithostratigraphique. *Sci. de la Terre* **17**, 273–288.

Horne, G. S. 1979. Mélange in the Trondheim Nappe suggests a new tectonic model for the central Norwegian Caledonides. *Nature, Lond.* **281**, 267–270.

Hossack, J. R. 1978. The correction of stratigraphic sections for tectonic finite strain in the Bygdin area, Norway. *J. geol. Soc. Lond.* **135**, 229–241.

Krill, A. G. in press. Tectonics of the Oppdal area, Central Norway. *Geol. För. Stockh Förh.*

Lagerblad, B. in press. Tectono-metamorphic development of the Gula Group—Fundsjø Group contact, central Norwegian Caledonides. *Geol. För. Stockh. Förh.*

Mykkeltveit, S. 1980. A seismic profile in southern Norway. *Pure appl. Geophys.* **118**.

Nicholson, R. 1979. Caledonian correlations: Britain and Scandinavia. In: *The Caledonides of the British Isles—reviewed* (edited by Harris, A. L., Holland, C. H. & Leake, B. E.). *Spec. Publ. geol. Soc. Lond.* **8**, 3–18.

Nilsen, O. 1973. Petrology of the Hyllingen gabbro complex, Sør-Trøndelag, Norway. *Norsk geol. Tidsskr.* **53**, 213–231.

Nilsen, O. 1978. Caledonian sulphide deposits and minor iron-formations from the southern Trondheim region, Norway. *Norg. geol. Unders.* **340**, 35–85.

Nystuen, J. P. in press. The Late Precambrian 'sparagmites' of southern Norway: a major Caledonian allochthon—the Osen-Røa Nappe Complex. *Am. J. Sci.*

Oftedahl, C. 1943. Om sparagmitten og dens skyvning innen kartbladet Øvre Rendal. *Norg. geol. Unders.* **161**, 1–65.

Oftedahl, C. 1956. Om Grongkulminasjonen og Grongfeltes skyvedekker. *Norg. geol. Unders.* **195**, 57–64.

Oftedahl, C. 1975. Middle Jurassic graben tectonics in mid-Norway. *Proc. Jur. North North Sea Symp.* Stavanger, 1–13.

Oftedahl, C. 1979. Hølonda–Horg area—tre separate skyvedekker (The Hølonda–Horg area—three separate nappes). *Abs. Norsk Geol. Forening, Ann. Meeting,* Trondheim, January 1979, 35.

Oftedahl, C. 1980. Geology of Norway. *Norg. geol. Unders.* **356**, 1–114.

Olesen, N. Ø., Hansen, E. S., Kristensen, L. H. & Thyrsted, T. 1973. A preliminary account on the geology of the Selbu–Tydal area, the Trondheim region, Central Norwegian Caledonides. *Leid. geol. Meded.* **49**, 259–276.

Peacey, J. S. 1964. Reconnaissance of the Tømmerås anticline. *Norg. geol. Unders.* **227**, 13–84.

Pidgeon, R. T. & Råheim, A. 1972. Geochronological investigations of the gneisses and minor intrusive rocks from Kristiansund, central Norway. *Norsk geol. Tidsskr.* **52**, 241–256.

Prost, A. E., Guezou, J.-C., Point, R., Quenardel, J.-M., Santarelli, N., Henry, A. & Ellenberger, F. 1977. Une transversale dans les Calédonides Scandinaves Centrales: du socle Baltique à la côte Atlantique. *Revue Géogr. phys. Géol. dyn.* **19**, 481–502.

Roberts, D. 1967. Structural observations from the Kopperå-Riksgrense area and discussion of the tectonics of Stjørdalen and the NE Trondheim region. *Norg. geol. Unders.* **245**, 64–122.

Roberts, D. 1971. Stress regime and distribution of a conjugate fold system from the Trondheim region, central Norway. *Tectonophysics* **12**, 155–165.

Roberts, D. 1972. Penecontemporaneous folding from the Lower Palaeozoic of the Trondheimsfjord region, Norway. *Geol. Mag.* **109**, 235–242.

Roberts, D. 1978. Caledonides of south central Norway. *Geol. Surv.. Pap. Can.* **78–13**, 31–37.

Roberts, D. 1980. Mélange in the Trondheim Nappe, central Norwegian Caledonides. *Nature, Lond.* **285**, 593.

Roberts, D. 1980. Petrochemistry and palaeogeographic setting of the Ordovician volcanic rocks of Smøla, Central Norway. *Norg. geol. Unders.* **359**.

Roberts, D. & Sturt, B. A. 1980. Caledonian deformation in Norway. *J. geol. Soc. Lond.* **137**, 241–250.

Rui, I. 1972. Geology of the Røros district, south-eastern Trondheim region, with a special study of the Kjøliskarvene–Holtsjøen area. *Norsk geol. Tidsskr.* **52**, 1–21.

Ryan, P. D., Williams, D. M. & Skevington, D. 1980. A revised interpretation of the Ordovician stratigraphy of Sør–Trøndelag. *Proc. IGCP Symp.* Blacksburg, Virginia, 99–103.

Råheim, A. 1977. A Rb, Sr study of the rocks of the Surnadal syncline. *Norsk geol. Tidsskr.* **57**, 193–204.

Siedlecka, A. 1967. Geology of the eastern part of the Meråker area. *Norg. geol. Unders.* **245**, 22–58.

Siedlecka, A. 1975. Old Red Sandstone lithostratigraphy and sedimentation of the Outer Fosen area, Trondheim region. *Norg. geol. Unders.* **321**, 1–35.

Siedlecka, A. & Siedlecki, S. 1972. A contribution to the geology of the Downtonian sedimentary rocks of Hitra. *Norg. geol. Unders.* **275**, 1–28.

Size, W. B. 1979. Petrology, geochemistry and genesis of the type area trondhjemite in the Trondheim region, central Norwegian Caledonides. *Norg. geol. Unders.* **351**, 51–76.

Stephansson, O. 1976. A tectonic model of the Offerdal–Olden area, Jämtland. *Geol. För. Stockh. Förh.* **98**, 112–119.

Strand, T. 1961. The Scandinavian Caledonides: a review. *Am. J. Sci.* **259**, 161–172.

Sturt, B. A. 1978. The Norwegian Caledonides—introduction. *Geol. Surv. Pap. Can.* **78–13**, 13–15.

Sturt, B. A., Miller, J. A. & Fitch, F. J. 1967. The age of alkaline rocks from West Finnmark, northern Norway, and their bearing on the dating of the Caledonian orogeny. *Norsk geol. Tidsskr.* **47**, 255–273.

Törnebohm, A. E. 1888. Om Fjällproblemet. *Geol. För. Stockh. Förh.* **10**, 328–336.

Törnebohm, A. E. 1896. Grunddragen af det centrala Skandinaviens bergbyggnad. *Kgl. Svenska Vetensk. Akad. Handl.* **28**, 1–212.

Vogt, Th. 1936. Orogenesis in the region of Palaeozoic folding of Scandinavia and Spitsbergen. 16*th Int. Geol. Congress*, Washington 1933.

Vogt, Th. 1940. Geological notes in the *Dictyonema* locality and the upper Gauldal district in the Trondheim area. *Norsk. geol. Tidsskr.* **20**, 171–192.

Vogt, Th. 1945. The geology of part of the Hølonda–Horg district, a type area in the Trondheim region. *Norsk geol. Tidsskr.* **25**, 449–528.

Vokes, F. M. & Grenne, T. 1978. Grønnsteins geokjemi og sulfiddannelse i den kaledonske fjellkjede. IGCP Delprosjekt **D48**, 22–12. Unpublished Annual Report, 56–61.

Wilson, M. R., Roberts, D. & Wolff, F. C. 1973. Age determinations from the Trondheim region Caledonides, Norway: a preliminary report. *Norg. geol. Unders.* **288**, 53–63.

Wolff, F. C. 1967. Geology of the Meråker area as a key to the eastern part of the Trondheim region. *Norg. geol. Unders.* **245**, 123–146.

Wolff, F. C. 1976. Geologisk kart over Norge, berggrunnskart Trondheim 1 : 250 000. *Norg. geol. Unders.*

Wolff, F. C. 1979. Beskrivelse til de berggrunnsgeologiske kart-bladene Trondheim og Østersund, 1 : 250 000. *Norg. geol. Unders.* **353**, 1–77.

Wolff, F. C. & Roberts, D. 1980. Geology of the Trondheim region. *Norg. geol. Unders.* **356**, 117–128.